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(NASA-CR-149993) ANALYTICAL STUDY OF
ELECTRICAL DISCONNECT SYSTEM FOR USE ON
MANNED AND UNMANNED MISSIONS Interim Report
(Martin Marietta Aerospace, Denver, Colo.)
31 p HC \$4.00

N76-32463

Unclas
CSCL 09A G3/33 03486

MCR-76-393

August 1976

INTERIM REPORT

ANALYTICAL STUDY OF ELECTRICAL
DISCONNECT SYSTEM FOR USE ON
MANNED AND UNMANNED MISSIONS

Contract NAS8-31971

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FOREWORD

This interim report describes the functional requirements established for the Electrical Disconnect System and the results of the connector survey. This report was prepared as partial fulfillment of Contract NAS8-31971 for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center. The NASA Contracting Officer's Representative was Mr. Wayne J. Shockley of the Electronics and Control Laboratory.

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1.0 INTRODUCTION

The objective of this contract is to establish an optimum electrical disconnect system design(s) for use on manned and unmanned missions. The purpose of the disconnect system is to electrically mate and demate the spacecraft to subsystem module interfaces to accomplish orbital operations.

This interim report presents the results of Task 1 and Task 2 of the contract effort. Task 1 involves the definition of the functional, operational, and environmental requirements for the connector system to support the leading prototype candidate concepts. Task 2 involves the documentation review and survey of available existing connector designs.

The requirements definition and potential applications for the electrical disconnect system is presented in Section 2.0. In Section 3.0, results of Task 2 are presented including the visitation of two NASA contractor original equipment manufacturers and five electrical connector suppliers. Also included is the documentation research. Section 4.0 presents the conclusions as a result of completing Tasks 1 and 2.

2.0 POTENTIAL APPLICATIONS AND REQUIREMENTS (Task 1)

This section of the interim report presents the results of Task 1 of the contract effort. In Section 2.1, potential applications of electrical disconnect systems for Shuttle-era spacecraft are discussed. The functional, operational, and environmental requirements for electrical disconnects for use on manned and unmanned missions are defined in Section 2.2. The details which form the basis of this report were derived from available Shuttle Orbiter, Spacelab, and payload requirements documentation. The disconnect applications identified were derived from consideration of the philosophy of spacecraft refurbishment, servicing, or repair to increase lifetime and reduce costs.

2.1 Potential Applications

Figure 1 below summarizes the steps utilized to identify specific potential applications of electrical disconnect systems for this contract effort. It should be noted that each mission and payload type was examined against each possible task opportunity. The specific technique used to accomplish the identified task for a given payload was then identified (IVA, EVA, or remote).

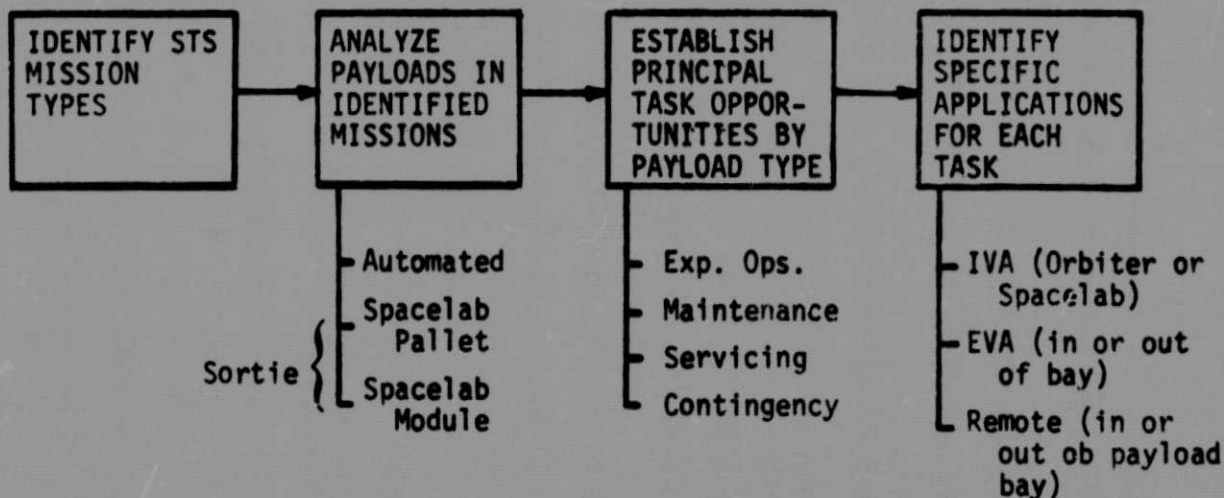


Figure 1 Identification of Electrical Disconnect Applications (STS-Related)

2.1.1 STS Missions and Payloads Analysis - The Space Transportation System (STS) includes the Shuttle Orbiter with its cargo bay, which can carry payloads such as automated spacecraft, the Interim Upper Stage (with attached spacecraft), pallet-mounted experiments, or the pressurized Spacelab module. Mission models prepared by the NASA for the 1980's indicate that many combinations of payloads make up the projected missions.

For the purposes of this study, mission configurations are not as important as the characteristics of the major payload types. Sortie payloads are those payloads which are carried into orbit in the Orbiter cargo bay, and which remain in the bay for the entire flight. The payloads or experiments are mounted on pallets and are controlled either from the ground, the Orbiter aft flight deck, or from the Spacelab pressurized module also mounted in the cargo bay. Thus, sortie payloads implicitly rule out the repositioning or reconfiguration of equipment during flight and, therefore, limit the requirement for electrical disconnects except in contingency modes.

Automated payloads are autonomous spacecraft which are carried into orbit in the cargo bay and either deployed directly or carried to operational orbit by an Interim Upper Stage (IUS). Such payloads--particularly if designed to be on-orbit maintainable (as opposed to expendable or ground-refurbishable)--may directly require the use of electrical disconnect systems for normal operations. Table 1 shows a list of automated payloads which might require such systems.

2.1.2 Principal Task Opportunities - As listed in Figure 1, the general tasks which might involve electrical disconnect systems can be categorized as experiment operations, maintenance, servicing, or contingency procedures. In general, nominal experiment operations (for any payload) do not include mating/demating of electrical connectors. (The only identified potential exceptions to this are two Life Sciences experiments which include instrumentation to be utilized both in the Orbiter AFD and in the pressurized Spacelab module.)

Pallet and module payloads are generally not designed for on-orbit servicing or maintenance. Particularly for early Shuttle missions, which will be of seven days duration, payloads should not require replenishment of supplies, subsystem changeout, or any similar activities. Only in the case of contingency operations may there be a requirement for electrical disconnect systems to be available in the Orbiter AFD, Spacelab module, or on the pallet.

For automated payloads, as Table 1 shows, maintenance or servicing operations in orbit are anticipated. Of course, all such procedures would be performed in the space environment using either remote systems or an EVA crewman. Present IUS ground rules specify that no recovery of the IUS (or its payload) will be performed; therefore, disconnect system requirements should be emphasized for low earth orbit spacecraft only (deliverable directly by Shuttle). Several techniques have been defined to perform such servicing/maintenance remotely, and these include a pivoting arm servicer, the Shuttle remote manipulator system (RMS), the flight support system (FSS), and the remote maneuvering unit (RMU). Specific EVA operations have also been defined for such payloads as the Space Telescope.

Table 1 Automated Payloads/On-Orbit Maintainable

Payload Number	Payload Model Code No.	Spacecraft Name
AS-01-A	AST-6	Space Telescope
AS-03-A	AST-1B	Cosmic Background Explorer
AS-05-A	AST-1C	Advanced Radio Astronomy Explorer
AS-07-A	AST-N1	3m Ambient Temperature IR Telescope
AS-11-A	AST-N2	1.5m IR Telescope
AS-13-A	AST-N3	UV Survey Telescope
AS-14-A	AST-N4	1m UV Optical Telescope
AS-16-A	AST-8	Large Radio Observatory Array
AS-17-A	AST-N5	30m IR Interferometer
HE-01-A	AST-9B	Large X-Ray Telescope Facility
HE-03-A	AST-5A	Extended X-Ray Survey
HE-05-A	AST-5D	High Latitude Cosmic Ray Survey
HE-07-A	PHY-1A	Small High Energy Satellite
HE-08-A	AST-5B	Large High Energy Observatory A
HE-09-A	AST-4	Large High Energy Observatory B
HE-10-A	AST-5C	Large High Energy Observatory C
HE-11-A	AST-9A	Large High Energy Observatory D
HE-12-A	PHY-5	Cosmic Ray Laboratory
SO-02-A	AST-7	Large Solar Observatory
SO-03-A	AST-3	Solar Maximum Mission
AP-01-A	PHY-1B	Upper Atmosphere Explorer
AP-02-A	PHY-1C	Explorer - Medium Altitude
AP-04-A	PHY-2A	Gravitational and Relativity Satellite - LEO
AP-05-A	PHY-3A	Environmental Perturbation Satellite - A
AP-07-A	PHY-3B	Environmental Perturbation Satellite - B
EO-08-A	EO-3	Earth Observatory Satellite
EO-09-A	EO-4	Synchronous Earth Observatory Satellite
EO-10-A	EO-5	Applications Explorer (Special Purpose Satellite)
EC-12-A	EO-6	TIROS
EO-56-A	NN/D-8	Environmental Monitoring Satellite
EO-57-A	NN/D-9	Foreign Synchronous Meteorological Satellite
EO-58-A	NN/D-10	Geosynchronous Operational Meteorological Satellite
EO-59-A	NN/D-12	Geosynchronous Earth Resources Satellite
EO-61-A	NN/D-11	Earth Resources Survey Operational Satellite
EO-62-A	NN/D-13	Foreign Synchronous Earth Observation Satellite
OP-02-A	EOP-5	Gravity Gradiometer
OP-04-A	EOP-7	GRAVSAT
OP-05-A	EOP-8	Vector Magnetometer Satellite
OP-51-A	NN/D-14	Global Earth and Ocean Monitoring System
LS-02-A	LS-1	Biomedical Experiment Scientific Satellite
CN-51-A	NN/D-1	INTELSAT
CN-52-A	NN/D-2A	DCMSAT A
CN-53-A	NN/D-2B	DOMSAT B
CN-54-A	NN/D-3	Disaster Warning Satellite
CN-55-A	NN/D-4	Traffic Management Satellite
CN-56-A	NN/D-5A	Foreign Communication Satellite - A
CN-58-A	NN/D-2C	DOMSAT C
CN-59-A	NN/D-6	Communications R&D Prototype

Contingency operations on automated payloads may also be possible, either remotely or EVA, but would primarily involve the same disconnect requirements as defined for planned servicing or maintenance.

Table 2 summarizes specific task opportunities for each major payload type.

Table 2 Disconnect System Task Opportunities by Payload Type

General Task	PAYLOAD TYPE			
	Automated	Pallet Only	Spacelab Module	Orbiter AFD
Experiment Ops			X (limited)	X (limited)
Maintenance	X			
Servicing	X			
Contingency	X	X	X	X

2.1.3 Specific Applications/Technique - The general tasks identified in paragraph 2.1.2 above must in general be accomplished by either direct EVA techniques, remote EVA (manipulator systems), or by IVA in the Orbiter or Spacelab pressurized environments. Some of the activities related to automated payloads might be completed by any of the EVA techniques. Specific examples of each application can be cited.

Servicing of the Space Telescope, for example, will be performed by direct EVA in the subsystems or science instrument modules. The flight support system (FSS) is the intended servicer for such spacecraft as the Earth Observatory Satellite and the Solar Maximum Mission. The pivoting arm servicer might be utilized on the Large High Energy Observatory. The remote manipulator system (Shuttle) can assist in the scheduled or contingency maintenance activities of the other systems, including EVA assistance. The remote maneuvering unit can perform activities outside the Orbiter payload bay at distances of up to 30 km from the Orbiter. The application of disconnect systems to IVA for Life Sciences experiments has already been noted.

All these general tasks may involve cable to cable, cable to equipment, and equipment to equipment connections, with some restrictions based on operational requirements. Maintenance tasks performed remotely, for example, are essentially blind connections between modules. IVA requirements could include both cable to cable and cable to equipment applications.

Such considerations allow definition of the functional, operational, and environmental limits within which electrical disconnect systems must perform. Detailed requirements in each of these areas were generated based on the anticipated potential applications.

2.2 Requirements

The overall requirements which electrical disconnect systems must satisfy are largely defined by the tasks which they must perform. They must operate properly in space vacuum and in the Orbiter or Spacelab pressurized environment. They must allow operation (mate/demate) with bare hands (IVA), with pressurized EVA gloves, or remotely (blind connection).

The following paragraphs summarize the requirements for electrical disconnect systems in terms of functional, operational, and environmental criteria.

2.2.1 Functional Requirements - These requirements relate to the characteristics of the disconnect system, independent of the environments and conditions to which they may be subjected. These requirements are as follows.

2.2.1.1 System - The disconnect system must connect/disconnect electrical connections in both a controlled environment and the environments of outer space. The connect/disconnect functions will be manually accomplished by manned EVA or remote servicing methods. The design goal of the system is to provide a low cost, simple, and reliable design. The system shall consider vibration and mechanical shock requirements coupled in both the hot and cold extremes of paragraph 2.2.3.

2.2.1.2 Connector Contacts and Inserts - The connector for the system must meet the requirements of NASA-MSFC specifications 40M39580, 40M38277, and 40M39569 for only the following components of the connector:

- Contacts per 40M39580;
- Contact sealing per 40M39580;
- Inserts per 40M39580;
- Finishes;
- Design and construction;
- Insert arrangements;
- Shell sizes;
- Contact current carrying sizes per 40M39580.

2.2.1.3 Latching Method - The connector latching method (if required) must be compatible with the end effector on the servicing mechanisms which allow rotation and lateral motions. Any rotational coupling technique must be less than 1.57 rad (90°). Preferred coupling is axial, push-pull actuating mechanism. The latching method shall be mechanical and shall provide forces to lock the connector halves together when mated. On demating,

the latching method must release and allow separation of the connector. The connector coupling lock mechanism shall be designed to accommodate remote operation as well as IVA hand and EVA suited glove operation.

2.2.1.4 Mating and Unmating Mechanism - Mechanism shall be designed to minimize the force required to initially align and affix the mating connectors followed by the required coupling force. The reacting coupling forces shall be confined within the coupled connectors to the greatest extent possible. The connector system must withstand retract and extraction forces applied to the module translated by orbital servicing mechanisms and hand tools.

2.2.1.5 Connector Housing - The connector housing shall be scoop-proof and explosion-proof by virtue of sealing the housing before electrical contact is made. Mounting means shall include a hermetic seal capability to the black box or subassembly.

2.2.1.6 Materials - The materials to be utilized in the system shall tentatively conform to the requirements of the NASA-MSFC 40M39569. This tentative selection is valid until future testing data under the environmental extremes of para 2.2.3 is available to verify adequacy of material during cycling connection/disconnections.

2.2.1.7 Alignment Features - The connector system shall incorporate an alignment feature which allows angular and floating tolerances of the orbital servicing mechanisms to final mating of the plug/receptacle to within the tolerances for pins and sockets required in the 40M39580 specification. The use of auxiliary pilot/guide hardware and increased leads shall be considered. Locksmith keying polarization features of current 40M connectors shall be utilized.

2.2.1.8 Voltage Levels - The disconnect system shall be designed for the following voltage levels:

- 5 to 32V DC;
- 115V AC, 60 Hz;
- 115V AC, 400 Hz.

2.2.1.9 Durability - The connector system shall withstand 500 cycles of connect/disconnect.

2.2.2 Operational Requirements - Operational requirements relate to the actual techniques which will be utilized to connect and disconnect the electrical components. These techniques are separable into two major categories--remote (blind) connections and operations performed directly by a crewman.

2.2.2.1 Remote Connections - The connectors must allow mating/demating by remotely controlled equipment (orbiter servicer or manipulator arm). The remote connections can be classified as RMS or rack and panel applications and the requirements are as follows:

A. RMS Applications:

Alignment Tolerance (design connector to accommodate or eliminate) ± 3.81 cm (± 1.5 in.), 300 S (± 5 min.).

Force to Mate/Demate - Less than 6.81 kg (15 lbs) - any greater force requirement must be accommodated by latching mechanism on the end effector.

Provide Alignment Guides and Pin Protection as Required (Alignment guides may be located on the module/equipment).

Maximum Cycle Time - 300 S (5 minutes).

B. Rack and Panel Applications:

Utilize existing MSFC specifications 40M38277 and 40M39569 less coupling sleeve.

2.2.2.2 Manned Operations - The requirements listed here are for connectors operated by an EVA crewman with the suit pressurized to 3.5 psi. Mating/Demating of the connectors shall be able to be accomplished utilizing the requirements of 2.2.2.1A and within the following limits:

- Maximum hand rotation required - less than 1.57 rad (90°);
- Maximum grip strength required (without tool usage) - less than 15.89 kg (35 lbs);
- Maximum torque required (without tool usage) - less than $.230 \times 10^{-3}$ M - kg (20 in.-lb);
- Design for one-hand operation;
- Design to preclude damage to pressure suit;
- Verify (by procedure) power removed prior to connect/disconnect;
- Design to protect pin contacts;
- Provide alignment and polarization cues as required;
- Minimum connector diameter - 1.59 cm (5/8 inch).

Manned operations of the disconnect system as an IVA exercise should conform to the same general requirements. Although force and torque capabilities in the pressurized environment are greater, and design constraints in the absence of the need for an EVA glove are less severe, the same requirements should be utilized in disconnect system design.

2.2.3 Environmental Requirements - Electrical disconnect systems must operate in the pressurized Orbiter environment, the pressurized Spacelab module, the unpressurized payload bay, or completely external to the Orbiter vehicle. The disconnects must withstand launch and reentry environments in the above locations, and must allow connect/disconnect operations to be conducted during on-orbit periods. General requirements are described in the following paragraphs.

2.2.3.1 Orbiter Pressurized Environment - The following are applicable as design to environment:

- Pressure

- a. Ground

- (1) Structural Leak Check - $2.07 \times 10^5 \text{ n/M}^2$ (30.0 psia) max
 - (2) Operational Leak Check - $1.24 \times 10^5 \text{ n/M}^2$ (18.0 psia) max
 - (3) Ambient - $.85 \times 10^5 \text{ n/M}^2$ (12.36 psia) to (15.23 psia) $1.05 \times 10^5 \text{ n/M}^2$
 - (4) pp O_2 - $.22 \times 10^5 \text{ n/M}^2 \pm .017 \times 10^5 \text{ n/M}^2$ (3.2 \pm 0.25 psia)

- b. Orbital Mission

- (1) Range - $.95 \times 10^5 \text{ n/M}^2$ (13.7 psia) to $1.10 \times 10^5 \text{ n/M}^2$ (16.0 psia)
 - (2) Emergency - $.55 \times 10^5 \text{ n/M}^2$ (8.0 psia) max $9.9 \times 10^3 \text{ sec}$ (165 minutes) maximum

- Temperature

- a. Ground

- (1) Atmospheric and Structural - 274.82°K (35°F) to 322.04°K (120°F)

- b. Ferry Flight

- (1) Atmospheric and Structural - -249.82°K (-10°F) to 305.37°K (+90°F)

- c. Orbital Flight

- (1) Atmospheric - 291.48°K (65°F) to 305.37°K (90°F)
 - (2) Structural - 289.26°K (61°F) to 322.04°K (120°F)

- Humidity

- a. Ground - 8 to 100% RH

- b. Orbital Mission - 85% RH maximum at 291.48°K (65°F) dry bulb; 17% RH minimum at 305.37°K (90°F) dry bulb.

- Lightning - Refer to MF0004-002.

- Shock - All components shall be designed to withstand a 20g terminal sawtooth shock pulse of an 11 millisecond duration in each of three orthogonal axes (6 directions).

- Acceleration - Ultimate steady state acceleration from 0 to $\pm 5\text{g}$'s in each direction of each major axis.

- Structural Vibration - TBD

2.2.3.2 Payload Bay - The following are applicable as design to environments:

- Pressure

- Ground - $.85 \times 10^5 \text{ n/M}^2$ (12.36 psia) to $1.05 \times 10^5 \text{ n/M}^2$ (15.23 psia)
- Ferry Flight - $.23 \times 10^5 \text{ n/M}^2$ (3.28 psia) to $1.05 \times 10^5 \text{ n/M}^2$ (15.23 psia)
- Orbital Mission - $1.33 \times 10^{-8} \text{ n/M}^2$ (1×10^{-10} Torr) to $1.05 \times 10^5 \text{ n/M}^2$ (15.23 psia)
- Approach and Landing Test - $.23 \times 10^5 \text{ n/M}^2$ (3.28 psia) to $.96 \times 10^5 \text{ n/M}^2$ (13.9 psia)

- Temperature

- Ground - 242.59°K (-23°F) to 338.71°K (150°F)
- Ferry Flight - 219.26°K (-65°F) to 327.59°K (130°F)
- Orbital Mission - 88.71°K (-300°F) to 372.04°K (210°F)
- Approach and Landing Test - 233.15°K (-40°F) to 338.71°K (150°F)

- Solar Radiation - assume $18.1 \times 10^9 \text{ J/M}^2/\text{s}$ (443.7 BTU/ft²/hr)

- Shock - All components shall be designed to withstand a 20g terminal sawtooth shock pulse of an 11 millisecond duration in each of three orthogonal axes (six directions).

- Acceleration - see table below.

Orbital Mission Crash Safety Load Factors

	g_x +Aft	g_y +Right	g_z +Up
Zone 1*	+20.0	+3.3	+10.0, -4.4
Zone 2**	+ 9.0 - 1.5	+1.5	+4.5, -2.0
Zone 3***	No crash load factor requirements		

Zone 1 (20g's)

- a. Flight deck (Sta. 439 to Sta. 576, above Z° 419)
- b. Mid-deck (Sta. 387 to Sta. 576, Z° 328 to Z° 419)

Zone 2** (9g's)

- a. Forward RCS package
- b. Mid. fuselage
 - (1) Equipment bay (below Z° 330)
 - (2) Payload attachment
 - (3) Manipulator arm attachment

Zone 3*** (No requirement)

- a. All other areas of Orbiter Space

Load factor is equivalent to the total externally applied load on the component divided by the component weight, and carries the sign of the total externally applied load.

2.2.3.3 Spacelab Pressurized Module Environment - Environmental requirements for equipment contained in the Spacelab module are detailed in Section 5.0 of the *Spacelab Payload Accommodation Handbook*, Estec Reference No. SLP/2104.

3.0 DOCUMENTATION RESEARCH AND SURVEY (Task 2)

3.1 Documentation Research and Review

The purpose of this activity was to perform documentation research and review to investigate and to relate Martin Marietta experiences associated with those connectors used in previous NASA programs and to determine their technical suitability or design characteristics for possible consideration for use in manned and unmanned maintainable spacecraft connector applications.

3.1.1 Review of NASA Project Parts Lists - This activity involved the review of selected project parts lists which prescribed preferred connectors for the past Skylab program and for the current Space Shuttle program. The Jet Propulsion Laboratory (JPL) and Goddard Space Flight Center (GSFC) parts lists for general space projects were also reviewed. Brief abstracts of this research follow.

1. Skylab Program, *Preferred Electrical Parts List for Apollo Applications Program*, MSFC Document 85M02716, Revision C, dated 25 June 1972.

This document lists the MSFC 40M39569 connector as the sole, preferred, miniature, circular connector. Listing of the MSFC 50M02340 TNC series and MIL-C-39012/1, /3 N Series coaxial radio frequency connectors are also included.

2. Skylab Program, *Skylab Program, MMC Skylab Experiments EEE Parts List*, JSC Document MSC-00841, EL40-001, Revision 8, dated 15 May 1972.

This document lists the MSFC 40M39569 miniature circular, the 40M39580 zero-g, and various project-peculiar Martin Marietta-use connectors, including the Air Lock/Microdot astronaut connector, for use on the various Skylab experiment, instrumentation, TV communication, and Multiple Docking Adaptor end items. The predominant-use 40M39569 and 40M39580 and Air Lock/Microdot connectors are considered to be the most technically viable candidates for use in manned and unmanned maintainable spacecraft applications. Other project-peculiar connectors were of specialized design and of limited application and would offer no significant design features which could be effectively adapted to meet the objectives of this study.

3. Space Shuttle Program, *EEE Parts Selection and Application Guidelines for the Space Shuttle External Tanks and Solid Rocket Booster (ET and SRB)*, MSFC document 85M03936, Revision B, dated 15 February 1975.

This document lists the MSFC 40M39569 miniature circular, the 40M39580 zero-g, and the 40M38277 high density circular connectors. These connectors are considered as those which currently possess the most favorable design characteristics or features best suited for possible use in manned and unmanned maintainable spacecraft applications.

4. Space Shuttle Program, *Electrical, Electronic, and Electromechanical Orbiter Project Parts List*, Rockwell International (RI) document MF0004-400, Revision A, Sequence 03, dated April 1976.

This document lists the MSFC 40M39569 miniature and 40M38277 high density circular connectors, and the RI project-peculiar ME414-0611 hermetic feedthrough, ME414-0235 straight plug, ME413-0234 wall-mount receptacle connectors, MC414-0343 TNC coaxial, and MC414-0344 HN coaxial connectors. Connector accessories for the multi-contact connectors are also listed including the short clamp nut, backshell with straight strain relief, and backshell with right-angle strain relief. The latest addendum also adds notation that the 40M connectors have not qualified to the Orbiter temperature (specifically, to 116.48°K (-250°F)) and vibration requirements. This effort is in process at RI. The MSFC connectors are the preferred items used in current NASA projects for general cable hook-up applications. The ME414-0234 and -0235 connectors are of the MIL-C-5015, MS3450 type with crimp, removable contacts, threaded coupling design, and constructed with space-compatible materials. The RI project-peculiar connectors are listed with limited shell sizes and insert arrangements primarily for size 0, 4, and 8 contacts for power applications.

5. General Space Applications, *Preferred Materials, Fasteners, Processes, and Packaging and Cabling Hardware*, Jet Propulsion Laboratory document JPL-STD-00009, Revision A, dated April 1976.

This document lists specialized, custom connectors procured to JPL specification 20045/2-0 for the MIL-C-24308-type, subminiature "D" rectangular, rack-and-panel, solder contact type, and JPL specification 2245-0300 for the MIL-C-26482, MS3100-series, circular, solder contact type connectors. A limited-use, rectangular, rack-and-panel separation connector is also listed for specialized applications. These connectors are uniquely utilized in scientific spacecraft designs and possess no substantial features which would meet the basic design requirements for this study.

6. General Space Applications, *GSFC Preferred Parts List*, GSFC document PPL-12, dated July 1972, with Notice 2, dated August 1973.

This document lists GSFC specifications S-311-P-10 and S-311-P-4/5 for MIL-C-24308-type, subminiature "D" rectangular, rack-and-panel connectors of the solder and crimp contact types and containing quantities of 9, 15, 25, 37, and 50 contacts and the MIL-C-22557 miniature, screw-on, coaxial, radio frequency connectors for flight usage. Similar to JPL applications, these connectors are utilized in specialized applications and lack the necessary features required for maintainable spacecraft applications.

3.1.2 Review of MSFC Connector Specifications - This effort involved the review of each of the current MSFC 40M series specifications--40M38268, 40M38277, 40M38294, 40M38298, 40M39569, and 40M39580--to ascertain their technical suitability or adaptation for use in manned and unmanned maintainable spacecraft applications. Since these connectors, with the exception of the 40M38277, 40M38294, and 40M38298 connectors which were not available, performed satisfactorily in the Skylab program, their continued use in future projects, including the Space Shuttle program, warrants strong consideration. In that the newer 40M specifications are based essentially on the same material and performance requirements as their predecessors, that the conventional rotational bayonet-locking or threaded coupling mechanisms of these connectors may not be suitable for use in maintainable spacecraft; thus, a new type or altered mechanism may be required. The 40M39580 mechanism, specifically designed for astronaut use, does offer features which merit consideration for use in maintainable spacecraft applications, notably one-hand, axial push-pull actuation with minimal force required for initial alignment and coupling followed by increasing forces for seal and contact engagement. The design and construction of the 40M series connectors affecting contact installation, insert, and seal/grommet characteristics are acknowledged to be of the latest technological state of the art. The 40M series connector alignment and polarization features are consistent with current connector design; features affecting explosion- and scoop-proofing are lacking with the exception of the 40M39580 connector. The materials associated with these connectors, having previous Skylab experience associated with earth and on-orbit controlled and space environments, would also warrant continued use for maintainable spacecraft applications. The electrical and performance characteristics of the 40M series connectors are listed in Table 3.

3.1.3 Martin Marietta Related Experience - Martin Marietta served as the principal contractor for the Multiple Docking Adapter and a number of Skylab experiments. In addition to the MSFC 40M39569 and 40M39580 predominant-use connectors, approximately fifteen (15) project-peculiar specification control drawings were prepared to specify the unique requirements for connectors utilized in special applications. These included the heavy duty, power, and multicoaxial feed-through connectors used in the MDA penetrator to the microminiature, .127 cm (0.050 inch) centers, twist pin connectors used in various Skylab medical experiments.

TABLE 3 NASA-MSFC 40M SPECIFICATION SUMMARY

Specification No.	Description	Classification	Styles	Shell Sizes	Contact Sizes	Shell Mtl.	Shell Finish	Oprn. Temp.	MECHANICAL REQUIREMENTS			
									Cpling. T.	Durability	Vibration	Phys. Shock
MSFC 40M38268	Terminal Junction Assembly (See Remarks)											
MSFC 40M38277	Miniature, Circular, high density, low profile, bayonet cpling	Environmental(E), Hermetic (H)	Plug, St. Plug, Grd Plug, w/o cpl'g ring Recept, flg mtd Recept, jam nut Recept, solder mtd Recept, thru blkhd	8 thru 24	220	Al Alloy Carb. steel St. steel	Nickel Tin Pass'vte	+238°F to +342°F (for E) +238°F to +302°F (for H)	8 to 38 in-lbs	250 cycles	Sine: 10 to 55 Hz @ 325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/gct, 100 to 2000 Hz @ 1 g ² /Hz	1/2 sinewave, 75g 11 ms
MSFC 40M38294	Miniature, Circular, cryogenic, Thd'd Cpling	Environmental(E), Hermetic (H) Non-Envirn'tl(I)	Plug, Int'n'l Plug, Ext'n'l Recept, feed thru Recept, weld MT	8 thru 18, 22, 24	20,16,12, 8 coax	Al alloy St. steel	Nickel Pass'vte	+452°F to +392°F	No Seal	200 cycles	Sine: 10 to 55 Hz @ 325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/gct, 100 to 2000 Hz @ 1 g ² /Hz	1/2 sinewave, 75g 11 ms
MSFC 40M38298	Miniature, Circular, bayonet cpling, shell size 8	Environmental(E)	Plug, St Recept, Jam Nut	8 only	20	Al Alloy	Nickel	+238°F to +392°F	8 in-lbs	500 cycles	Sine: 10 to 55 Hz @ 325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/gct, 100 to 2000 Hz @ 1 g ² /Hz	1/2 sinewave, 75g 11 ms
MSFC 40M39569	Miniature, Circular, bayonet cpling	Environmental(E) Hermetic (H)	Plug, St. Plug, Grd Plug, w/o cpl'g ring Recept, flg mtd Recept, jam nut Recept, solder mtd Recept, thru blkhd	8 thru 24	20,16,12, 8 coax, 12 shld'd	Al alloy St. steel	Nickel Pass'vte	+238°F to +392°F (for E) +238°F to +302°F (for H)	8 to 38 in-lbs	500 cycles	Sine: 10 to 55 Hz @ 325 DA, 55 to 2000 Hz @ 50 g, Pk Rand: 20 to 100 Hz @ 6 db/gct, 100 to 2000 Hz @ 1 g ² /Hz	1/2 sinewave, 75g 11 ms
MSFC 40M39580	Circular, astronautous, push-pull cpling mechanism	Environmental(E) Hermetic (H) Cryogenic (C)	Plug, St. Recept, flg mtd Recept, jam nut	15,17, 21,25	20,16, 12,22D	Al alloy St. steel	Chrome Pass'vte	+85°F to +302°F (for E) +85°F to +302°F (for H): +42°F to +302°F (for C)	12 to 24 oz premate. 4 to 12 lbs cpling force	250 cycles	Sine: 10 to 55 Hz @ 325 DA, 55 to 2000 Hz @ 50g, Pk Rand: 20 to 100 Hz @ 6 db/gct, 100 to 2000 Hz @ 1 g ² /Hz	1/2 sinewave, 75g 11 ms

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REQUIREMENTS	ELEC. REQ'TS			MISC. REQ'TS			Remarks
	Phys. Shock	Contact Rating	DWV	Moist. Resistance	Explo. ATM	Scoop Proof	
							Not a disconnect-type device- not applicable for this study
NaO 325 PA, 50 Hz @ 50 g, Ph 0 Hz @ 6 db/gct, 800 Hz @ 1 g ² /Hz	1/2 sinewave, 75g, 11 ms	220: 5 Amps	1300 vac @ seal 350 vac @ 70k ft 200 vac @ 110k ft	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O, Mated, Energ- ized ckts	No	Space compatible mtlx- 9 insert arr'mts avail w/ 6 to 128 contacts, keying via key rotation. Used on Space Shuttle.
NaO 325 PA, 50 Hz @ 50 g, Ph 0 Hz @ 6 db/gct, 800 Hz @ 1 g ² /Hz	1/2 sinewave, 75g, 11 ms	20: 7.5A 16: 20A 12: 35A	1500/2300 vac @ Sea Level for Service 1/II; 375/550 vac @ 70k ft for I/II; 270 vac @ 110k ft for I & II; 200 vac @ 10 ⁵ mm Hg for I & II	10 cycles, 90 to 98% RH, 10°C to 65°C	No Req't	No	Space compatible mtlx- 13 insert arr'mts avail w/ 1 to 61 contacts, keying via key rotation. Used on Space Shuttle.
NaO 325 PA, 50 Hz @ 50 g, Ph 0 Hz @ 6 db/gct, 800 Hz @ 1 g ² /Hz	1/2 sinewave, 75g, 11 ms	20: 7.5A	1500 vac @ Sea L. 250 vac @ 110k ft 200 vac @ 10 ⁵ mm Hg	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O, Mated, Energized circuits	No	Mtlx same as 40M39569- 3 insert arr'mts avail w/ 2 to 6 contacts, keying via key rotation
NaO 325 PA, 50 Hz @ 50 g, Ph 0 Hz @ 6 db/gct, 800 Hz @ 1 g ² /Hz	1/2 sinewave, 75g, 11 ms	20: 7.5A 16: 20A 12: 35A	1500/2300 vac @ Sea Level, for Service I/II; 375/550 vac @ 70k ft for I/II; 250 vac @ 110k ft for I & II; 200 vac @ 10 ⁵ mm Hg for I & II	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O; mated, ener- gized ckts	No	Space compatible- mtlx, 29 insert arr'mts avail w/ 3 to 61 contacts, incl coaxial. Key- ing via insert rotation. Used on Skylab, Space Shuttle
NaO 325 PA, 50 Hz @ 50g, Ph 0 Hz @ 6 db/gct, 800 Hz @ 1 g ² /Hz	1/2 sinewave, 75g, 11 ms	220: 5A 20: 7.5A 16: 13A 12: 23A	1300/1500/2300 vac @ Sea Level for Service M/I/ II; 300/400/500 vac @ 50k ft; 200 vac @ 110k ft for M, I & II	10 cycles, 90 to 98% RH, 10°C to 65°C	7% H, 93% O; mated, ener- gized ckts	Yes	Space compatible mtlx- designed for one- hand opn, astronaut-use, 12 insert arr'mts avail w/ 6 to 61 contacts. Keying via roll pin a slot. Utilizes movable plug in- sert. Used on Skylab program

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The life-support umbilicals and TV communications system utilized the Air Lock/Microdot astronaut connector. Experience with these connectors showed their sensitivity to handling, particularly with the microminiature types. Fracture of plastic shells, bending of pin contacts, and connector damage caused during contact installation were the predominant problems encountered during fabrication. Also, difficulties were experienced in the proper termination and assembly of miniature and subminiature contacts used in the multi-coaxial connectors.

Problems associated with the 40M39580 zero-g connector involved coupling mechanism hang-up resulting from inner-to-outer shell binding and linkage action. Some problems were also experienced with incorrect installation of the peripheral dynamic seal. Pin-to-socket contact engagement adequacy was also investigated under worst-case connector mating conditions.

With the exception of the Air Lock/Microdot connector where it was determined that the contact engagement integrity was dependent on the location of the Air Lock shell with respect to the panel thickness and its tolerancing, all other critical use connectors showed satisfactory electrical engagement in excess of .127 cm (0.050 inch).

It is known that the high density-type connectors utilizing size 22 contacts and those common to the MIL-C-38999 specification (i.e., 40M38277 and 40M39580) are typically rated as minimal engagement in their design. The engagement integrity of the multi-coaxial and the MIL-C-39012 single coaxial connectors is also rated as minimal in the calculated engagement of approximately .025 cm (0.010-inch) under worst-case conditions. Any modification or redesign of these type connectors should include an assessment of contact engagement integrity to assure proper connector function.

A Martin Marietta connector study of single and redundant release systems associated with separation-type connectors was recently completed in March 1976 under contract to the U. S. Air Force. This study surveyed the current use separation mechanisms and presented factors which should be considered in the design of redundant release systems. The involvement of connector alignment, coupling, and release forces and retention reliability was also documented. The findings gained through this study would most likely have an influence on the design of coupling mechanisms for use in manned and unmanned maintainable spacecraft applications.

3.1.4 Research of Miscellaneous Related Documents - In addition to Martin Marietta previous experience on the Skylab program, a search was conducted to verify the actual in-flight experiences reported for the three (3) manned Skylab missions. Telephone conversations with MSFC and JSC personnel indicated that no significant connector concerns or problems were encountered as reported by the Skylab crews. Martin Marietta participants at each of the oral crew debriefings reported no serious connector problems or anomalies were presented including the specific address of the 40M39580 connector.

NASA Technical Memorandum, Report No. NASA TM X-64814, dated October 1974, entitled *MSFC Skylab Mission Report--Saturn Workshop*, was perused and confirmed that no major connector anomalies or difficulties were experienced by the crews. A damaged connector on the TV input station was the sole item discussed in this report and proved to be of no significant consequence. One comment suggested that improved markings on connector shells for visual alignment and locking indication be entertained as a future improvement.

NASA Technology Utilization Compilations, SP-5936(01), (02), and (03) on the subjects of cables and connectors and SP-5908(04) on hand tools were reviewed to obtain information which might be appropriate for this study. Of particular interest were those devices associated with the blind mating, alignment, non-arcing, and low-force coupling of connectors (SP-5936(01), five items) and a one-hand operated connector coupling tool [SP-5908(04)].

The Rome Air Development Center technical report *Reliability Study (of) Circular Electrical Connectors*, Report No. RADCR-73-171, dated June 1973, was reviewed to afford an in-depth baseline of connector statistical reliability data which was gained from this comprehensive study. The conclusions of this study indicate that ".... the best reliability and overall performance will be obtained either from MIL-C-38999, Series I, or from MIL-C-83723." The design of the 40M38277 Series connectors resembles the MIL-C-38999, Series I, parts with the basic exception that the 40M connectors are not scoop-proof; however, the preferred contact retention and insert design features are the same. The insert design of the 40M39580 Series connectors are identical to those of MIL-C-38999 and 40M38277 (for the size 22 contact arrangements).

3.1.5 Documentation Research and Review Summarization - The documentation research and review activity disclosed that the MSFC 40M series connectors possess the preferred design features of current connector state of the art. These connectors have satisfactorily demonstrated their physical and performance capability in their previous use in the Skylab program and are included in the preferred parts lists of the current Space Shuttle program. The evolution of connectors for use in manned and unmanned maintainable spacecraft warrants the strong consideration of the continued use of the 40M Series connectors. Modifications may be required to facilitate the coupling operation of these connectors to alter the method of actuation and to reduce forces. The 40M series connectors also offer diversified contact sizes and insert arrangements which would cover most electrical circuit requirements for use in maintainable spacecraft applications. A heavy duty connector may be required for certain power applications; a space-compatible connector of this type is currently listed for Space Shuttle usage as a project-peculiar part.

The availability of single-cable coaxial connectors appears to be limited and, by virtue of their design characteristics--especially size and coupling features--would require extensive modification or redesign to enable their use in maintainable spacecraft applications. The only

availability of multi-coaxial connectors are those limited arrangements included in the 40M39569 specification or as provided in the Air Lock/Microdot connector. Expansion may be required to facilitate additional coaxial requirements, if anticipated.

Rack-and-panel type connectors are not listed in previous or current NASA manned spacecraft project lists; inclusion of these parts are listed in scientific spacecraft parts lists but these afford no preferred design characteristics which would favor their utilization in manned or unmanned maintainable spacecraft applications.

3.2 NASA Contractor/Connector Supplier Survey

The survey involved visitation of two NASA contractor original equipment manufacturers (OEM)--Rockwell International Space Division (RI) and TRW--five (5) electrical connector suppliers who are currently listed as approved sources on various MSFC 40M Series connector specifications--G&H Technology, ITT Cannon Electric, Deutsch Company, Bendix ECD, and Burndy Corporation--and one (1) supplier of the astronaut suit connector--Air Lock, Inc.

3.2.1 NASA Contractor OEM Survey - Of the two OEMs visited, only RI has had previous experience associated with serviceable space flight connectors. These connectors were of the general types currently listed for use in the Space Shuttle Orbiter and the Shuttle External Tanks and Solid Rocket Booster preferred parts lists. RI also stated that they have had previous experience with the astronaut-use MSFC 40M39580 zero-g and Air Lock/Microdot connectors used on life support umbilical cables in the Skylab program. RI mentioned that various problems were encountered with previous-use connectors but none were considered to be of a major concern or catastrophic consequence and which were not satisfactorily resolved. A concern associated with the adequacy of contact engagement (pin height) and coupling mechanism actuation with the zero-g was reported and should be more thoroughly investigated for future use of this connector. TRW's expertise has been involved primarily with scientific satellites where nonserviceable, lightweight connectors have been exclusively utilized.

Both contractors indicated current participation in the Space Shuttle program. RI is the prime contractor for the Shuttle Orbiter and TRW is providing the Orbiter communications systems and a number of Shuttle payloads. Both OEMs indicated the preferred use of MSFC 40M39569 and 40M38277 connectors for the majority of the Shuttle applications. No explicit requirement currently exists to provide connectors suitable for on-orbit servicing. With the exception that RI is in current process of qualifying the 40M series connectors to a lower temperature capability 116.48°K (-250°F) than that currently specified 123.15°K (-238°F), all other requirements in the 40M specifications are deemed adequate for use in the Space Shuttle program. To date, no major connector application problems have been cited in conjunction with the Shuttle Orbiter or Shuttle communications systems. One contractor reported, however, that a continual concern

exists relative to the tearing of wire-seal grommets during contact installation and especially with the MSFC 40M38277 high density connector and that this concern is being resolved by training of assembly personnel.

For future or anticipated NASA projects, both contractors felt that the current state of the art for connectors would be satisfactory. This would indicate that the current connector materials and design characteristics for NASA space-use connectors would be adequate. Military specification versions would not, however, be suitable.

Specific address of factors affecting utilization of connectors for on-orbit manned (IVA, EVA) and unmanned (remote) space flight applications indicated that many uncertainties exist. One contractor reported that connectors anticipated to be used at the Shuttle Orbiter payload interface panels, payload operations stations, and prelaunch payload service panel have not been defined to date. This contractor is currently involved with the Space Shuttle System Payload Accommodations Study and expects that these connector requirements will soon be established. Until such time as more discrete connector maintainability/serviceability and performance requirements are evolved, no specific assurance could be established by the contractors as to the total adequacy of current available connectors. Both OEMs did agree that the available electrical contacts and connector inserts used in connectors listed for use in the Shuttle program would probably be satisfactory for anticipated maintainable spacecraft applications. One contractor did suggest that for weight and space savings, NASA should consider the incorporation of additional size 12, 16, and 20 electrical contacts in the MSFC 40M38277 specification. Both participants indicated that the present threaded and bayonet coupling features of current-use connectors would not be suitable for manned and unmanned spacecraft applications. In order to facilitate connector coupling/uncoupling in these applications, the present forces should be reduced most practically through the use of auxiliary or increased efficiency mechanisms. The use of in-line or axial actuating mechanisms would be preferred over the conventional rotating (bayonet or threaded) means for connector coupling. Innovations of the "zero insertion force" concept whereby connectors would be initially mated with no significant force and where secondary action is employed to effect contact engagement was favored by one contractor. Where force reductions cannot be practically reduced, particularly in large-size connectors, the use of coupling assist tools should be considered. It was also suggested that improved connector alignment features be developed to more positively assure proper engagement of connectors and especially for those remote applications where visibility is reduced or negated. Coincident with these factors, one OEM felt that the alignment features of current NASA-use connectors would be manageable for maintainable spacecraft applications whereas the other participant indicated that additional mismatch tolerancing of the present alignment features or the possible use of secondary alignment devices be utilized to facilitate connector coupling. No strong opinions were voiced relative to the adequacy of current available connector polarization features with the

exception that one contractor stated the current locksmith keying concept is preferred over the rotating insert method. A difference of opinion was expressed relative to the need for contact protection, or scoop-proofing. One contractor stated that scoop-proofing should be a mandatory requirement for all contact sizes whereas the other indicated that the present non-scoop MSFC 40M39569 and 40M38277 connectors would be suitable. Both OEMs indicated that explosion-proofing would not be necessarily a critical nor essential requirement for maintainable spacecraft applications. One contractor reported that their technical practices dictate that "live" circuits be de-energized whenever connectors are to be coupled or uncoupled.

Both contractors would subscribe to the use of the MSFC 40M38277, high-density, size 22 contact connector for maintainable spacecraft applications. As previously indicated, however, one contractor suggested the scoop-proof feature--and especially for size 22 electrical contacts--be incorporated in this connector. The contractors would also permit the use of hermetic seal connectors, as required, in spite of their susceptibility to damage of the annealed pin contacts. One contractor indicated their nonpreference of hermetic connectors was due primarily to the large increase of resistance or voltage drop with their use. One contractor stated the current connector cable accessories listed in the MSFC 40M series specifications would continue to be suitable; the other prefers not to use accessories but favors potting of connectors to provide strain relief and termination of shields. Both OEMs also stated reparability of connectors on-orbit would not be practical in that accessibility to component-installed receptacles or jacketed cable plugs would not be attainable. For contingency purposes however, the current state of the art construction characteristics of the MSFC 40M series connectors would permit their repair of discrete circuits.

Both contractors reported that the present single-cable coaxial and multi-coaxial connectors would not be suitable for use in maintainable spacecraft applications. Current NASA specifications for these connectors and contacts do not list impedance-control requirements, according to the participants, nor would the present products be totally suitable for S-band and higher frequencies. Also, single-cable coaxial connectors would require more manageable coupling mechanisms to facilitate their use but no practical suggestions were offered.

For modularization of maintainable spacecraft components as commonly designated space replaceable units (SRU), discussion centered on the use of rack-and-panel, blind mate connectors. Typically, these connectors would require alignment and coupling force capability through the facility of the module installation racking and securing support hardware. One participant stated that these type connectors are not preferred in their design of avionics systems in that the rack-and-panel connectors are more prone to contact damage and would require substantial strengthening of

avionics enclosures to withstand the ensuing connector mating forces and to provide axial tolerancing to assure proper connector engagement which might otherwise be jeopardized due to deflection of panel interfaces. The other contractor suggested that modification of present connectors may be required to facilitate their use in maintainable spacecraft applications. Both OEMs believed that the alignment and mateability features of current available rack-and-panel connectors should be improved. These would include the expanded use of dowel-and-cone piloting and more ample shell lead-in chamfers. Both participants also believed that the MSFC 40M39569 and 40M38277, Style 6W, plug-less-coupling ring connectors might be made adaptable for use in rack-and-panel applications to favor the availability of a wide variety of space-proven inserts and contacts; however, this adaptation could amount to a significant or substantial effort.

3.2.2 NASA Connector Supplier Survey - With the exception of two suppliers--G&H Technology and Burndy--all other suppliers indicated they had manufactured products used on the past Apollo and Skylab programs. All suppliers except Burndy stated they are currently involved with the Space Shuttle program. With the exception of two suppliers, all others generally felt the current connector state of the art, as typified in the MSFC 40M series specifications, would be adequate for future or anticipated NASA projects in that the realm of space environment characteristics has now been essentially established. One of the excepting suppliers believes new requirements may be established at the onset of any future program such as the Shuttle requirements for the MSFC 40M38294 cryogenic connector or for the unique Orbiter-to-747 Transport interface connector. The other excepting supplier feels the adequacy of present state of the art connector materials should be thoroughly investigated to establish their use in maintainable spacecraft applications. This concern relates to the functional capability of connectors which would be exercised (i.e., coupled/uncoupled) in the space environment and particularly at the extreme cold temperature 123.15°K to 116.48°K (-238°F to -250°F) where the elasticity of materials such as flexural elastomers may not function responsively to preserve or maintain the operational integrity of the connector. This supplier suggested new test criteria be evolved to require that, for on-orbit serviceability applications, connectors be coupled/uncoupled at the extremes of applicable space environments and, with special consideration of the Shuttle mission profile, the repeated cyclic requirement of the earth launch--on--orbit--earth return environments.

With specific address of connector maintainability in manned (IVA, EVA) and unmanned (remote) space flight applications, the MSFC 40M series circular connector suppliers felt the current 40M series electrical contacts and connector inserts would effectively satisfy those requirements affecting material suitability and quantified application demands for electrical circuitry. The current available rotational MSFC 40M series coupling mechanisms would not be suitable according to the 40M suppliers. One supplier felt their proprietary breech locking mechanism characterized by a 1.57 rad (90-degree) maximum rotation and a $.253 \times 10^{-3}$ m-Kg (22 inch-pound) (maximum) torque would satisfy manned requirements. Other suppliers suggested that an axial, push-pull actuation

would best suit both manned and unmanned applications. One supplier felt that the MSFC 40M39580 zero-g connector mechanism would warrant continued use for manned applications and could be modified, if required, to facilitate use with manipulator mechanisms. Another supplier disclosed that a competitive design to the zero-g connector was generated during the Skylab program for presentation to MSFC but was not pursued due to its timeliness. The details of this connector design were not revealed during this survey but would be available through MSFC. The air lock/Microdot push-pull mechanism is of a frictional-fit design relating directly to the contact engagement and peripheral O-ring frictional forces. No mechanical advantage is offered with this coupling concept. The suppliers concurred that the present coupling forces should be reduced. These forces are essentially attributed to contact engagement/separation forces and environmental and interfacial seal compression. These forces could best be compensated for by providing more efficient coupling mechanisms to increase the mechanical advantage for the operator (man or mechanical manipulator).

The use of compression springs remains the principal source of stored energy to assist in the coupling/uncoupling activity where the increased mechanical advantage attained with helical ramping or screw threads may not be suitable for manned or unmanned applications. One supplier stated the coupling forces should be minimized at initial engagement and should gradually increase to effect the total coupling followed by force reduction to provide coupling assurance via "feel" as opposed to a constant, no-force variance effect. This concept is exemplified in the coupling action of the MSFC 40M39580 zero-g connector. It was also suggested that coupling/uncoupling forces and reactions be confined or contained at or within the connectors by squeezing actions of the hand or manipulator articulator as opposed to force transmission or reactance through the entire operator medium (human arm, body, or manipulator linkages, pivots/joints). Should force reductions not be practically attainable, then assisting power mechanisms or servicing tools may be required.

The suppliers were also of the opinion that probable connector access limitations would require that the alignment characteristics of the current MSFC 40M series connectors be modified, particularly for use with manipulators. More generous mismatch tolerancing should be provided by means of pre-engage connectors piloting through increased shell lead-in or funneling or by auxiliary guidance (i.e., dowel-and-cove) devices. The 40M suppliers confirmed that the current connector polarization characteristics were generally adequate--the locksmith keying concept was favored over the insert rotation design. The supplier of the MSFC 40M39580 zero-g connector acknowledged the previous problems associated with the roll-pin polarization device and suggested a coined/dimpled protrusion could be substituted in future products.

Most suppliers were not strongly opinionated as to the necessity for explosion-proofing of connectors. The predominant means of sealing off of interconnector insert void during engagement is with the use of peripheral O-rings or dynamic seals. Static discharging could be essentially suppressed through the grounding or contacting of engaging shells prior to

contact engagement. Three suppliers stated that scoop-proofing features should be incorporated in space application connectors, especially for size 20 electrical contacts--and smaller, to preclude inadvertent damage during handling.

One supplier recognized the coupling/uncoupling sensitivity for the use of single-cable coaxial connectors in manned and unmanned spacecraft applications and suggested the coupling mechanisms be redesigned, including significant enlargement, to provide a more manageable means of handling and actuation. Another possible means of modification would be to incorporate the internal elements of the single-cable coaxial connector into a conventional circular connector housing. Those suppliers involved with multi-coaxial connectors felt the present product availability, including the MSFC 40M39569 size 8 coaxial and size 12 shielded configurations would be adequate for future, general applications. One supplier stated that a GSFC concern exists relative to ".... the cascading VSWR oscillation effects..." which can result in the generation of excessive temperatures which could disintegrate the cable-to-contact termination and is tentatively attributed to the contact componentry/configuration and axial fit dimensional tolerances.

When queried as to the merits of the "zero insertion force" connector concepts for manned and unmanned spacecraft applications, no prevalent opinions were expressed with the exception that one supplier felt a "zero" initial mating force followed by a secondary actuation to engage the contacts (i.e., the MSFC 40M39580 zero-g connector concept) would be an approach to satisfy the minimal involvement to engage connectors and to confine the contact engagement forces within the coupled connectors.

In the address of rack-and-panel connectors for modularized SRU applications, three of four suppliers offering comments on this subject felt the current available rack-and-panel connectors would generally be suitable. The remaining supplier suggested that the alignment capability of the present connectors would not be adequate and that a new product featuring increased alignment capability and tighter dimensional product tolerancing--including tighter control of mounting provisions--is required. In effect, three suppliers recognized the alignment features of the present connectors should be improved by increasing shell lead-in or by use of auxiliary guide hardware to permit their use. One supplier suggested more emphasis on chassis guide provisions and the use of module guide pins would facilitate the continuing use of available rack-and-panel connectors. The possible use of fiber optics to ascertain proper connector alignment on a remote basis was also suggested. The suppliers generally agreed that the alignment features of existing connectors should be improved to the extent that maximum connector mismatch can be tolerated and the connectors physically engaged with minimal frictional forces and with resulting contact engagement within the allowable axial tolerances.

Three of four suppliers stated the MSFC 40M39569 and 40M38277, Style 6W, plugless coupling ring connectors would not be ideally suited for rack-and-panel applications in that these connectors possess no adequate, self-

contained alignment features whereas the remaining component suggested that these might be used only if critical adapter fixtures were evolved to permit "ganging" or multiple use of these connectors and would control their lateral and axial positioning to compensate for their lack of self-contained alignment. One supplier suggested the consideration of their circular, rack-and-panel connector for modularized SRU applications. This product is currently designed for an alignment mismatch of $\pm .157$ cm ($\pm .062$ inch) and could be modified to increase this allowance. It possesses a spring-loaded frontal protrusion feature which assures proper axial engagement. Current MSFC 40M series inserts could be installed in this product. This connector, however, does require additional force during mating to reposition the spring loaded connector.

It was disclosed by three suppliers that they were currently in process of responding to a GSFC quotation for rectangular, rack-and-panel connectors for Multimission Modular Spacecraft. The essential requirements for this connector-type include a ($\pm .012$ inch/ ± 10 degree) $\pm .030$ cm/.174 rad alignment mismatch, a mixed quantity of up to 160 various size power and coaxial contacts, friction-fit coupling, float-mounted plate, and blind mate capability. One supplier suggested an existing product would satisfy most of the GSFC requirements, whereas another proposed that a totally new concept should be evolved.

3.2.3 Survey Summary - The results of the survey to determine the availability of existing connector designs that may offer important design features may be summarized as follows.

The survey participants offered many helpful suggestions based on their past experiences and presentation of factors which, in their expertise, would most generally apply to the application requirements for maintainable, manned and unmanned spacecraft. However, since the survey inquiries dealt primarily on the basic or general concepts of connector maintainability, specific or total connector capabilities on design concepts could not be evolved. These detail features would be more firmly established when more specific mission and payload accommodation factors would be known such as connector accessibility including space occupancy/location, visibility limitations, module sizes, and specific electrical circuit requirements for any given payload or mission requirement.

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4.0 CONCLUSIONS

4.1 Utilization of Available Connector Designs

With a basic knowledge of manned and remote capability, the following predominant factors pertaining to the utilization of available connector designs were evolved.

4.1.1 Connector Contacts and Inserts - The current available MSFC 40M series electrical contacts and connector inserts could probably be utilized in future circular connectors for maintainable spacecraft applications.

4.1.2 Coupling Mechanisms - The current available rotational concepts (bayonet, threaded) for coupling/uncoupling of connectors should be modified to significantly reduce the coupling action to less than 1.57 rad (90 degrees) or, more preferably, replaced with axial, push-pull actuating mechanism. Emphasis should be placed on reducing the applied coupling forces to overcome contact engagement and seal compression inherent forces by increasing the efficiency and mechanical advantages of actuating mechanisms.

Mechanisms should be designed to minimize the force required to initially align and affix the mating connectors followed by the required coupling force. The reacting coupling forces should be confined within the coupled connectors to the greatest extent possible.

The existing requirements of the MSFC 40M39580 specification demand strong consideration as viable requirements for maintainable spacecraft applications. Certain modification of this connector's design features may be required to improve its operation and to adopt its use for unmanned applications.

4.1.3 Alignment Features - The alignment features of current available connectors should be improved to facilitate their ability to be properly coupled. The use of auxiliary pilot/guide hardware and increased leads should be considered. Locksmith keying polarization features of current connectors is preferred to prevent mismating of adjacent connectors.

4.1.4 Miscellaneous Connector Features - Scoop-proof connector features for all contact sizes should be considered to afford adequate protection of pin contacts. The necessity for explosion-proofing would be contingent on system parameters including combustible atmospheres and procedural requirements for the disruption of active electrical circuits.

4.1.5 Single Cable Coaxial Connectors

Use of single-cable coaxial connectors should be discouraged in that current available connectors are not deemed suitable for maintainable spacecraft application in terms of handling and actuation. Multi-coaxial applications should be more thoroughly investigated to determine the adequacy of current available configurations to meet performance (frequency, VSWR, impedance, etc) requirements.

4.1.6 Rack and Panel Connectors

Modular type, rack and panel connectors should be regarded as a separable connector design than that of hook-up, circular connectors due to their unique application. The rectangular connectors would appear to be most space-and-force efficient although the circular versions do offer the advantage of utilization of available inserts and contacts. The alignment features of the current available rack and panel connectors should be improved to facilitate their mateability in a more limited environment. More emphasis might be placed on the module racking and alignment provisions and tolerancing to minimize the need for extensive or elaborate connector alignment features.

4.1.7 Materials

Test criteria should be evolved to practically evaluate the adequacy of materials and mechanisms in selected space environments (i.e., temperature extreme of 88.71°K (-300°F) for male half being mated to 372.04°K (210°F) female half) to determine the ability of connectors to properly function and operate when coupled/uncoupled in these environments.

4.2 Requirements Summary

The following is a summary of the major functional and operational requirements.

4.2.1 System - The disconnect system must connect/disconnect electrical connections in both a controlled environment and the environments of outer space. The connect/disconnect functions will be manually accomplished by manned EVA or remote servicing methods. The design goal of the system is to provide a low cost, simple, and reliable design. In addition, the design for remote manipulator systems and for manned EVA applications shall be similar with the exception of a possible hand tool for latch/delatch.

4.2.2 Connector Contacts and Inserts - The connector for the system must meet the requirements of NASA-MSFC specifications 40M39580, 40M38277, and 40M39569 for only the following components of the connector:

- Contacts per 40M39580;
- Contact sealing per 40M39580;
- Inserts per 40M39580;

- Finishes;
- Design and construction;
- Insert arrangements;
- Shell sizes;
- Contact current carrying sizes per 40M39580.

4.2.3 Latching Method - The connector latching method (if required) must be compatible with the end effector on the servicing mechanisms which allow rotation and lateral motions. Any rotational coupling technique must be less than 1.57 rad (90°). Preferred coupling is axial, push-pull actuating mechanism. The latching method shall be mechanical and shall provide forces to lock the connector halves together when mated. On demating, the latching method must release and allow separation of the connector. The connector coupling lock mechanism shall be designed to accommodate remote operation as well as IVA hand and EVA suited glove operation.

4.2.4 Mating and Unmating Mechanisms - Mechanisms shall be designed to minimize the force required to initially align and affix the mating connectors followed by the required coupling force. The reacting coupling forces shall be confined within the coupled connectors to the greatest extent possible. The connector system must withstand retract and extraction forces applied to the module translated by orbital servicing mechanisms and hand tools.

4.2.5 Connector Housing - The connector housing shall be scoop-proof and explosion-proof by virtue of sealing the housing before electrical contact is made. Mounting means shall include a hermetic seal capability to the black box or subassembly.

4.2.6 Materials - Tentatively conform to NASA-MSFC 40M39569 requirements until testing program defined in 4.1.7 verifies acceptability.

4.2.7 Alignment Features - The connector system shall incorporate an alignment feature which allows angular and floating tolerances of the orbital servicing mechanisms to final mating of the plug/receptacle to within the tolerances for pins and sockets required in the 40M39580 specification. The use of auxiliary pilot/guide hardware and increased lead-in shall be considered. Locksmith keying polarization features of current 40M connectors shall be utilized.

4.2.8 Voltage Levels - The disconnect system shall be designed for the following voltage levels:

- 5 to 32 V DC;
- 115V AC, 60 Hz;
- 115V AC, 400 Hz.

4.2.9 Durability - The connector system shall withstand 500 cycles of connect/disconnect.

4.2.10 Remote Connections Requirements - The connectors must allow mating/demating by remotely controlled equipment (orbiter servicer or manipulator arm). The remote connections can be classified as RMS or rack and panel applications and the requirements are as follows:

A. RMS Applications:

Alignment Tolerance (design connector to accommodate or eliminate) ± 3.81 cm (± 1.5 in.), 300 S (± 5 min.).

Force to Mate/Demate - Less than 6.81 kg (15 lbs) - any greater force requirement must be accommodated by latching mechanism on the end effector.

Provide Alignment Guides and Pin Protection as Required (Alignment guides may be located on the module/equipment).

Maximum Cycle Time - 300 S (5 minutes)

B. Rack and Panel Applications:

Utilize existing MSFC specifications 40M38277 and 40M39569 less coupling sleeve.

4.2.11 Manned Operations Requirements - The requirements listed here are for connectors operated by an EVA crewman with the suit pressurized to 3.5 psi. Mating/demating of the connectors shall be able to be accomplished utilizing the requirements of 2.2.2.1A and within the following limits:

- Maximum hand rotation required - less than 1.57 rad (90^0);
- Maximum grip strength required (without tool usage) - less than 15.89 kb (35 lbs);
- Maximum torque required (without tool usage) - less than $.230 \times 10^{-3}$ M - kg (20 in.-lb);

- Design for one-hand operation;
- Design to preclude damage to pressure suit;
- Verify (by procedure) power removed prior to connect/disconnect;
- Design to protect pin contacts;
- Provide alignment and polarization cues as required;
- Minimum connector diameter - 1.59 cm (5/8 inch).

Manned operations of the disconnect system as an IVA exercise should conform to the same general requirements. Although force and torque capabilities in the pressurized environment are greater, and design constraints in the absence of the need for an EVA glove are less severe, the same requirements should be utilized in disconnect system design.